

1 **COMPACT HOLOGRAPHIC DATA STORAGE SYSTEM**

2 BACKGROUND OF THE INVENTION

3 1. Field of the Invention

4 The present invention relates to a compact holographic data storage
5 system, in particular to a holographic data storage system with high storage
6 density, small size and data-random-accessability.

7 2. Description of Related Arts

8 Holographic memory systems have immense potential for the future due
9 to their high capacity for data storage by various kinds of multiplexing recording
10 techniques and fast access time by signal parallel processing technique. There
11 has been extensive research in holographic memory, but it has not been
12 extensively used in consumer oriented data storage media. The main limitation
13 for conventional holographic memory systems is that their sizes too big for
14 installation in consumer-oriented electronic products. Because of the lack of
15 simple optical architecture and a compact light source with high power, the
16 conventional holographic memory systems are hard to be widely used. With the
17 recent advance in the manufacturing technology of solid-state laser diodes, there
18 has been small size, high power and wavelength-changeable commercialized
19 products of them. As for the optical system of holographic memory, some
20 compact designs have been already proposed,. Therefore many conventional
21 bottlenecks of holographic recording technique has been gradually overcame
22 with the advance of its related technologies and time passing.

23 The compact holographic memory system looks even more promising
24 than the popular optical disk memory system in that the holographic memory

1 system does not require media rotation for data retrieval and storage, and does
2 not have to be circular shaped. In general, the holographic medium for a
3 holographic memory system is usually created as a cube shape (approx. 1x1x1
4 cm³) or a rectangular parallel pipe. Therefore, by using compact optical system
5 design and high power laser diode, holographic memory systems can be
6 produced in sizes even smaller than conventional optical disks.

7 The block diagram of a holographic data storage system in one prior art
8 patent is shown in Fig. 13. When the system is in recording mode, a laser light
9 source (835) passing through a beam splitter (836) is separated and modulated to
10 become a signal beam (831) and a reference beam for writing in data (820). The
11 above signal beam (831) is further passed through another beam splitter (833) to
12 cause the laser beam to be directed toward an opto-electronic integrated circuit
13 (804).

14 The detailed diagram of the opto-electronic integrated circuit (804) in
15 Fig. 14 reveals that pixels are arranged thereon in matrix format (806), each pixel
16 containing a modulator (824) and a detector (823). The modulators (824) are
17 used to modulate a signal beam (826) to carry a digital image of the write data
18 into a crystal cube (802). The above modulated signal beam (826) and the
19 reference beam (820) of the write data will cross over each other in the crystal
20 cube (802), and produce an interference pattern, which will then be recorded in
21 the crystal cube (802).

22 If the system proceeds to record the next digital image, a diffraction
23 element (810) is needed to change the incident angle of the reference beam (820)
24 into the crystal cube (802) to enable another data recording

1 When the system is in data readout mode, after the laser light source (835)
2 passes through the beam splitter (836), the signal beam (831) will be masked,
3 leaving only the reference beam (820) to be guided through the diffractive
4 component (810) to change the direction of the reference beam (820) and reach a
5 self-pumped phase conjugator (832). The self-pumped phase conjugator (832)
6 then generates a counter propagating reference beam (821) casting onto the
7 crystal cube (802), where a reconstructed beam (825) is generated towards the
8 opto-electronic integrated circuit (804). Each detector (823) matching a
9 respective pixel (806) in the opto-electronic integrated circuit (804) will then
10 read out the digital image stored therein. If the system proceeds to read out the
11 next digital image, the diffractive optical element (810) is needed to change the
12 incident angle of the reference beam into the crystal.

13 However, the above mentioned prior art patent has several shortcomings:

14 (1) the opto-electronic integrated circuit (804) is too complicated for
15 commercial production;

16 (2) the detector (823) and the modulator (824) matching against each
17 pixel (806) cannot be disposed in the same position, therefore a reconstructed
18 beam (825) is required for supplementing the biasing angle; and

19 (3) the design and architecture of the whole optical system involves high
20 costs in actual implementation.

21 A holographic optical system with simpler and cost effective
22 architecture can be constructed with the present invention.

23 SUMMARY OF THE INVENTION

24 The main object of the present invention is to provide a holographic

1 memory system with high recording density 、 compact size and data random
2 access. The architecture of the holographic memory system in accordance with
3 the present invention includes:

4 a volume holographic recording medium for storing superimposed
5 interference patterns;

6 a laser emitting assembly having a large output area for emission of
7 parallel laser beams with different wavelength and proper cross sectional shape;

8 a beam splitter being disposed in the optical path of the parallel beams
9 for separating out a portion of the parallel beams to generate a reference beam;

10 a beam steering system for steering the separated reference beam, such
11 that the reference beam can be directed to predetermined positions on a volume
12 holographic recording medium with proper incident angles;

13 a phase modulator being disposed in the optical path of the reference
14 beam for generating beams with different cross-sectional phase distribution
15 patterns; and

16 a spatial light modulator as two-dimensional grating format being
17 disposed in the optical path of the parallel beams for holographic data input;

18 a photo detector as two dimensional grating format for detecting the
19 reconstructed signal after the reference beam is propagated to the volume
20 holographic recording medium, during data read from the volume holographic
21 recording medium.

22 The features and structure of the present invention will be more clearly
23 understood when taken in conjunction with the accompanying drawings.

1 BRIEF DESCRIPTION OF THE DRAWINGS

2 Fig. 1 is the system architecture of the present invention;

3 Figs. 2, 3 are the schematic diagrams showing the holographic signal
4 input/output paths in accordance with the first embodiment of the invention;

5 Figs. 4, 5 are the schematic diagrams showing the holographic signal
6 input/output paths in accordance with the second embodiment of the invention;

7 Figs. 6, 7 are the schematic diagrams showing the holographic signal
8 input/output paths incorporating a phase modulator in the third embodiment of
9 the invention;

10 Fig. 8 is a diagram of a spatial phase modulator made from transmissive
11 type LCD in the path of reference beam ;

12 Fig. 9 shows the use of several laser diodes as light source with different
13 wavelength selectively feeding through a cylindrical collimator;

14 Fig. 10 shows a spatial multiplexing recording by only changing the f
15 reference beam incident position into recording medium;

16 Fig. 11 shows a angle multiplexing recording by only changing the
17 reference beam incident angle into recording medium;

18 Fig. 12 shows a beam splitter for reference beam in accordance with one
19 embodiment of the invention;

20 Fig. 13 is the structural diagram of a conventional holographic memory
21 system;

22 Fig. 14 is a diagram of an opto-electronic integrated circuit revealing
23 detailed architecture of the pixel array.

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

2 The present invention provides a holographic memory system
3 comprising:

4 a volume holographic recording medium (10) that can be used to store
5 superimposed holographic interference patterns, and the material used on the
6 diffractive crystals can be $\text{LiNbO}_3\text{:Fe}$, BaTiO_3 , or other organic photo-sensitive
7 materials;

8 a laser emitting assembly (20) for emitting diverging laser beams
9 through a cylindrical collimated lens (30) and a rectangular aperture (31)
10 becoming parallel beams with different wavelength and cross sectional phase
11 distribution;

12 a beam splitter (50) disposed in the optical beam path for separating out a
13 portion of the parallel beams;

14 a beam steering system (60) for steering the reference beam output from
15 the beam splitter (50), such that the reference beam can be modulated to the
16 volume holographic recording medium (10) with proper tuning of the mirror
17 position and reflective angle;

18 a phase modulator (61) being disposed in the optical path of the reference
19 beam for generating a different cross sectional phase distribution; and

20 a spatial light modulator (40) represented by two-dimensional grating
21 format for data input into the volume holographic recording medium (10);

22 a photo detectors (70) in grating format for reading out data from the
23 volume holographic recording medium (10), such that each detector (70) is able
24 to sense the presence of a regenerated signal after the reference beam enters the

1 volume holographic recording medium (10).

2 Fig. 2 shows data entering the holographic memory system for data write
3 to the volume holographic recording medium (10). Two coherent beams enter the
4 volume holographic recording medium (10) and cross over each other to produce
5 a three-dimensional interference pattern which is then imparted on the volume
6 holographic recording medium (10) with a particular wavelength. When writing
7 in data, the laser emitting assembly (20) provides a parallel laser beam with
8 proper wavelength and cross sectional phase profile. A beam splitter (50)
9 disposed in the optical path of the reference beam intercepts a portion of the
10 parallel beams to produce a write reference beam. In the current implementation
11 the beam splitter (50) is implemented by a first reflective mirror (mirror1), which
12 intercepts the parallel beams to enter the beam steering system (60) formed by
13 the second reflective mirror (mirror2) and the third reflective mirror (mirror3).

14 The remaining portion of the parallel beams passes through the spatial
15 light modulator (40). In the current embodiment the modulators (40) in grating
16 format are implemented by a transmissive LCD panel serving as the holographic
17 input apparatus. The parallel beams pass through the transmissive LCD panel and
18 becomes an objective signal beam then cast onto the volume holographic
19 recording medium (10). The write reference beam emitted from the beam
20 steering system (60) enters the volume holographic recording medium (10) with
21 a proper incident angle and fincident position to proceed with the spatial and
22 angular multiplexing recording. Each incident position and angle of the incident
23 beam is matched against a respective particular data page in the volume
24 holographic recording medium (10).

1 The above mentioned write reference beam and signal beam will
2 interfere with each other in the volume holographic recording medium (10), and
3 the interference of two beams will produce a unique spatial pattern in accordance
4 with the electromagnetic intensity imparted on the volume holographic recording
5 medium (10). The spatial interference pattern will be stored in the volume
6 holographic recording medium (10). If there is another page of data to be
7 recorded, the data will be input in like manner through the transmissive LCD
8 panel. Selecting a different incident angle and position of reference beam, the
9 second page of data will be successfully recorded in the volume holographic
10 recording medium (10).

11 Fig. 3 shows data read out path from the volume holographic recording
12 medium (10). The LCD panel will be completely covered to shut off all light
13 beams. At the same time the incident angle and position of reference beam
14 corresponding to the data page in the volume holographic recording medium (10)
15 are selected to guide the reference beam to a particular data page in the volume
16 holographic recording medium (10). When the read reference beam touches the
17 interference pattern corresponding to the selected data page, a diffraction beam,
18 the reconstruction of signal beam, will be produced, and the diffraction beam will
19 be projected towards a photo detector (70), which is implemented by a charge
20 couple detector (CCD) camera in the current embodiment, such that the CCD
21 camera will be able to retrieve the data from a selected position of the volume
22 holographic recording medium (10). It is preferred that the pixel positions and
23 number of pixels on the CCD camera should be able to match against the
24 corresponding pixel positions and total number of pixels on the LCD panel.

1 The relative positions of the first reflective mirror (mirror1) and the
2 second reflective mirror (mirror2) can be adjusted to suit the thickness of the
3 beam slices. It should be noted that the first reflective mirror (mirror1) should not
4 enter the lower portion of the spatial light modulator (40) to avoid cutting off the
5 parallel beams passing through the LCD panel. The third reflective mirror
6 (mirror3) is movable or rotatable to adjust the horizontal position and reflective
7 angle for propagating the reference beam to the predetermined incident position
8 with proper incident angle. When the system records data on different pages, the
9 write reference beam should be directed to proper mirror positions and reflective
10 angles. This is a combinational approach from the spatial multiplexing and
11 angular multiplexing techniques conventionally used for a holographic recording
12 medium.

13 The above mentioned spatial light modulator (40) are implemented by a
14 transmissive LCD panel in the preferred embodiment. The on/off status of all
15 pixels on the LCD panel represents a data page on a two-dimensional plane.
16 When the parallel beams derived from the laser emitting assembly (20) pass
17 through the transmissive LCD panel, a grating pattern composing of light gating
18 components is created thus becoming the signal beam, which then enters the
19 volume holographic recording medium (10) for data recording. When the system
20 reads out data as shown in Fig. 3, all pixels on the LCD panel are covered to cut
21 off all light.

22 The second embodiment of the invention is shown in Figs. 4, 5. The
23 basic operating principles are similar to those shown in Figs. 2, 3, except that a
24 reflective LCD panel is employed as the spatial light modulator (40) instead of

the transmissive LCD panel with proper set up of the first reflective mirror (mirror1), that means the second reflective mirror (mirror2) is not necessary in the present configuration.

A modified version of the first implementation using phase code multiplexing is shown in Figs. 6 7. A phase modulator (61) is disposed in the optical path of the reference beam in the beam steering system (60) to enable the production of different cross sectional phase distribution of the reference beam, such that a reference beam having a particular cross sectional phase distribution, mirror position and reflective angle can be used for writing data to or reading out data from a particular page of the volume holographic recording medium. In this embodiment, the phase code multiplexing recording is introduced. The phase modulator (61) is implemented by a fully transmissive LCD panel as shown in Fig. 8. The phase modulator (61) is able to produce different phase delays for parallel beams passing through the beam steering system (60) from different positions. In the current embodiment, the phase delay pattern is in the form of long streaks. The beams passing through the same streak will possess the same phase delay characteristics. The longer side of the streaked parallel pipe is parallel to the longer side of the long and narrow cross-section of the reference beam in the beam steering system (60).

Another implementation of the invention with wavelength multiplexing is shown in Fig. 9. The wavelength of the laser beam from the laser emitting assembly (20) can be changed selectively. The laser emitting assembly (20) may be implemented with a laser diode with variable wavelength or a group of laser diodes with different wavelength (the example used in Fig 4 has four laser

1 diodes). When the light source is composed of multiple laser diodes with
2 different wavelength, a servo system is required to select a laser diode having the
3 selected wavelength which is then fixed in the center position of the focus area of
4 the cylindrical collimated lens. When the light passes through the cylindrical
5 collimated lens and the rectangular aperture, parallel laser beams with proper
6 cross sectional shape and wavelength are generated to proceed with the
7 wavelength multiplexing recording. A reference beam having a particular cross
8 sectional phase distribution and particular incident position and angle is able to
9 control write data to or read data from a predetermined page of the volume
10 holographic recording medium.

11 Besides, for a simple and cost effective system design, certain
12 multiplexing functions may have to be sacrificed. In one case, the system
13 employs a single wavelength laser diode as the light source to simplify the servo
14 mechanism of the holographic memory system. In another case, the system, as
15 shown in Fig. 10, by sacrificing the benefits of angular multiplexing, the beam
16 steering system (60) employs the adjustment of mirror position to modulate the
17 reference beam, whilst keeping with a fixed light reflective angle; or else, the
18 system, as shown in Fig. 11, may also be modified to only allow changes in
19 reflective angle but keeping with a fixed mirror position, thus sacrificing the
20 benefits of spatial multiplexing. If the system does or not use phase modulator
21 (61) for the reference beam, it has sacrificed phase code multiplexing.

22 An implementation of a beam splitter for reference beam is shown in Fig.
23 12, in which the laser beams are routed through a cylindrical collimated lens, and
24 further through a square aperture (31) and a narrow rectangular aperture (32), to

1 reach a spatial light modulator (40), and the parallel laser beams are routed
2 through the rectangular aperture (32) to enter the beam steering system (60).
3 Under the above architecture, the first and second reflective mirrors (mirror1 and
4 mirror2) are not required.

5 In the beam steering system (60) mentioned above, the system includes
6 several reflective mirrors controlled by a servo motor used for controlling the
7 mirror position and reflective angle. Using this means to modulate the reference
8 beam to the holographic medium, the spatial multiplexing recording and angular
9 multiplexing recording can thus be performed. When a phase modulator (61) is
10 disposed in the optical path of the beam steering system (60), a different cross
11 sectional phase distribution of the reference beam can be produced for the phase
12 code multiplexing recording.

13 To avoid the use of any mechanical means for adjusting the mirror
14 position and reflective angle, an opto-electronic beam steering device can be
15 employed in the beam steering system (60) to change the incident position and
16 angle of the reference beam without adjustment of mirror position and angle.

17 It will be appreciated that a compact holographic recording system using
18 the above mentioned multiplexing recording techniques or a combination thereof
19 can be constructed by any person with ordinary skill in the art, without departing
20 from the scope of the invention. The foregoing description of the preferred
21 embodiments of the present invention is intended to be illustrative only.